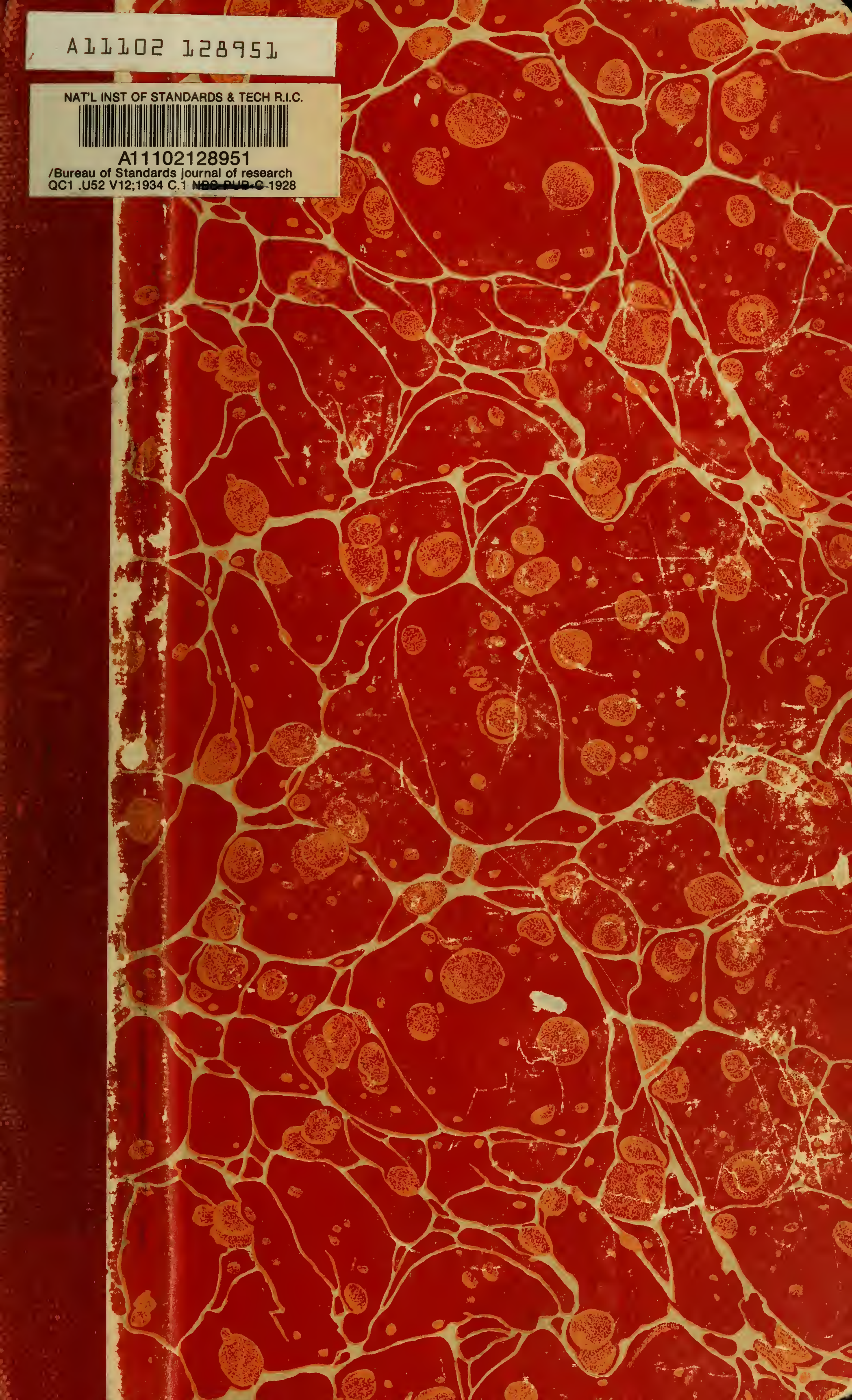

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A PORTABLE ULTRAVIOLET INTENSITY METER, CONSISTING OF A BALANCED AMPLIFIER, PHOTOELECTRIC CELL, AND MICROAMMETER

By W. W. Coblentz and R. Stair

ABSTRACT

A description is given of the construction and performance of a portable ultraviolet intensity meter, consisting of a photoelectric cell (of titanium, uranium, cadmium, etc.), a balanced amplifier circuit, and a comparatively insensitive microammeter.

A means is described for testing the constancy of the sensitivity of the amplifier. It is found that, after preliminary operation for 5 to 10 minutes, to attain temperature equilibrium in the amplifier tubes, there is no fluctuation in the zero scale reading of the microammeter either when testing the amplification sensitivity of the instrument, or when making measurements of ultraviolet intensities, of the sun and of artificial sources, by means of the photoelectric cell.

The indicator response (scale reading) was found linear within the accuracy of the microammeter used.

Owing to the selective wave length response of the photoelectric cell, this device, like all selective radiometers, is calibrated in absolute value, by means of the standard balanced thermopile and filter radiometer ("differential actinometer") described in RP370 and RP450.

CONTENTS

Page
I. Introduction 231
II. Description of the electric circuit 233
III. Performance tests 235
IV. Bibliography 236

I. INTRODUCTION

Since the advent of the thermionic ("radio") tube, about 3 decades ago, a number of arrangements of electric circuits have been proposed for amplifying small unidirectional electric currents, such as are obtained from thermopiles and photoelectric cells.

However, but few of these proposals have survived; and only within the past few years has substantial progress been made in devising means for the precise amplification and measurement of the small electrical currents available in radiometry.

This is owing partly to the general complexity and instability of the electronic circuit (which is sensitive to electrostatic disturbances), and partly to the lack of provision for electrically standardizing the amplifier—a necessary procedure since there is no convenient source of ultraviolet, of sufficient constancy, for use as a standard in calibrating the combined radiometer (photoelectric cell) and radio amplifier.

The situation is somewhat similar to that experienced in connection with the use of a thermopile connected with a Thomson galvanometer (8).[1]

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[1] Figures in parenthesis here and throughout the text indicate references and notes given in the bibliography at the end of this paper.

Owing to the varying current sensitivity of the galvanometer, the scale reading is evaluated, at frequent intervals, by means of an auxiliary electric circuit (consisting of a dry battery and suitable resistances) which provides a constant electric current, of an arbitrarily chosen magnitude that insures accuracy in reading the galvanometer scale.

Since the radiation sensitivity of the thermopile (in air) is subject to but little, if any, change with usage, the combination (consisting of the thermopile and galvanometer) is calibrated, at infrequent intervals, in absolute units, by means of a standard of radiation (2).

Based upon the results obtained in standardizing the Thomson galvanometer scale reading (8), in the present investigation a somewhat analagous procedure was adopted for calibrating the combined amplifier and microammeter scale reading—the microammeter, by itself, being subject to practically no variation in sensitivity. That is to say, the constancy of the scale reading of the microammeter, when used in connection with the radio amplifier (but separate from the photoelectric cell), is determined by means of an auxiliary electrical circuit (consisting of a voltmeter, dry battery, and resistances) so arranged that, when an arbitrarily chosen but constant emf is impressed upon the amplifier, the microammeter scale reading is a convenient magnitude that can be read accurately.

Since, as already mentioned, there is, as yet, no simple standard of ultraviolet radiation for accurately testing the constancy of the photoelectric cell (which is subject to a slow change in sensitivity with usage) it is desirable to provide several cells, one or more of which are kept in reserve and used infrequently as standards, for testing the constancy of the cells that are in regular use.

The microammeter scale reading, for the complete assembly (photoelectric cell, amplifier, and microammeter, etc.) is calibrated in absolute units by means of a standard balanced thermocouple and filter radiometer, or so-called "differential actinometer" (1). Such a calibration is necessary for each type of source used in ultraviolet radiation therapy.

In a previous communication (1) a description was given of the calibration, in absolute units, of a portable Rentschler ultraviolet meter, which consists of a titanium or uranium photoelectric cell, connected with an electron discharge tube and an automatic counting device. By using a number of photoelectric cells, all intercompared (when new) against a source of ultraviolet, then several kept in reserve as standards, it was possible to determine (without reference to a standard source of ultraviolet) whether a certain photoelectric cell or the electron discharge tube had changed with prolonged usage.

In the present communication a description is given of the performance of a portable ultraviolet intensity meter, consisting of a photoelectric cell (of titanium, uranium, cadmium, sodium, etc.,) connected to a balanced amplifier circuit (which is essentially a Wheatstone bridge), and a relatively insensitive microammeter. No attempt is made to use a balanced photoelectric cell circuit (3) by connecting two photoelectric cells in opposition (thus completing the analogy with the balanced thermocouple and filters), (1), because the additional complications do not appear to be necessary to meet our present requirements.

While but little novelty can be claimed for present-day amplifier circuits, involving the Wheatstone bridge principle (4), the manner in which the present amplifier device was worked out (principally by Stair) to meet the foregoing specifications, and the manner of testing the constancy of the amplification, is described in the following caption.

II. DESCRIPTION OF THE ELECTRIC CIRCUIT

The amplifier circuit, shown in figure 1, is essentially a Wheatstone bridge in which the arms R_1 and R_2 are two similar resistances (each of 100,000 ohms), and the arms T_1 and T_2 are two vacuum tubes (type 32, screen grid), which are as nearly identical as can be obtained commercially.

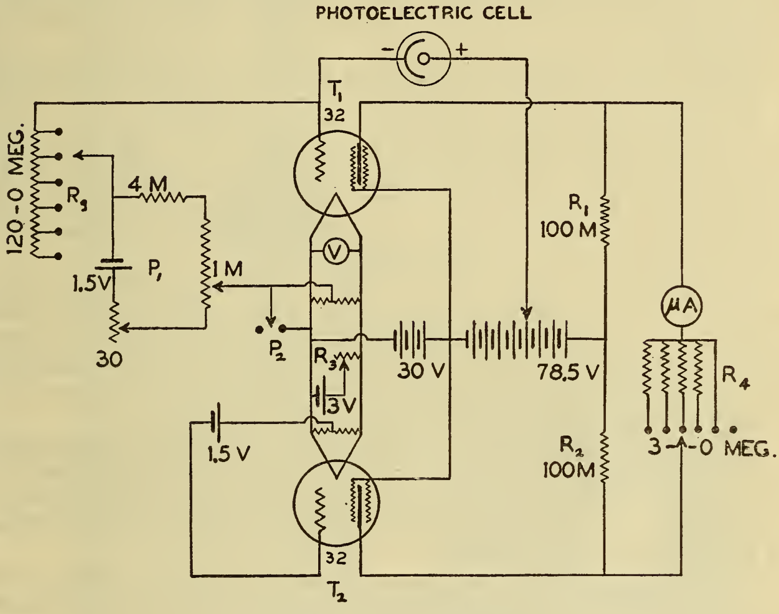

Figure 1.—*Wiring diagram.*

The pair of tubes employed were chosen after an examination of the characteristic curves of a number of tubes of this type. Contrary to some writers, there was no difficulty in finding pairs (or triplets) of tubes having practically identical characteristics; and the characteristics of these pairs are so closely the same that they can be interchanged in this assembly without modification of the resistances in the circuit. These pairs and triplets are, therefore, being held in reserve for replacements.

The use of matched vacuum tubes is a further modification of the electric circuit originally developed by P. I. Wold; improved by Wynn-Williams, by Eglin, and by Razek and Mulder; and recently discussed in detail by Nottingham (4).

In the present circuit, the grid potential of the tube, T_2, is placed at a fixed negative value, in the region of the flat portion of the positive ion, grid current curve; and near the lower end of the straight portion of the plate current vs. grid voltage curve of the particular tubes used. This is in contrast with the floating grid, or semifloating grid potential often used. The use of the type 32 screen grid tube greatly reduces the grid current difficulties in an amplifier of this type.

Since the grid of the tube T_2 is at a fixed potential, and that of T_1 is always adjusted to a similar value, by means of the potential varying device P_1, the voltage sensitivity of the amplifier remains the same regardless of the resistance, R_g. This is not the case where the grid potential of the tube, T_2, also changes, as occurs with a change of grid resistances, used for increasing the current sensitivity.

In order to test the amplifier sensitivity from day to day, the potential changing device, P_2, is incorporated. By means of this control the grid potential of the tube T_1 can be changed, at will, by a definite amount, thus giving a measure of the voltage sensitivity of the amplifier.

A balance of the amplifier (indicated by no current flowing through the microammeter, fig. 2) is obtained by adjusting P_1. Since T_1 is closely identical to T_2, the final grid voltage of T_1 (with no current flowing through the photoelectric cell and R_g) will be very closely the same as that of T_2. It could be made exactly the same by the incorporation of variable resistors in the filament circuit and (or) the plate circuit of one of the tubes. This latter refinement has not been found necessary in the present work.

Since closely identical tubes are used in a balanced circuit with the same plate, screen grid, and filament batteries for both tubes, small variations in voltage are unimportant. Furthermore, since no additional battery is necessary in connection with the use of the microammeter or other sensitive indicating device, the danger of injury to the meter is avoided when the filament circuit is opened.

The dry batteries, resistors, radio tubes, and meters are mounted upon a chassis, which includes a hard-rubber insulating support for the control switches, etc. This support is covered with a sheet of aluminum, suitably perforated to permit access to the control switches, and for viewing the meters.

The complete assembly is inclosed in a metal box, as shown in the photograph, figure 2, for protection against electrostatic disturbances. A further elimination of electrostatic variations is obtained by covering the binding post, connected with the control grid of the active radio tube, with a metal cap, no. 7, figure 2. Inclosing the photoelectric cell in a metal housing is also desirable to reduce electrostatic disturbances when making measurements out of doors when there is a strong wind.

The controls indicated in figure 2, serve the following purposes: nos. 1 and 3 (P_1 in fig. 1) are commercial resistances of 1,000 and 30 ohms (for coarse and fine adjustment), respectively, for regulating the control grid voltage of the active tube, in order to adjust the microammeter (to right in fig. 2) to the zero scale reading; no. 2(R_3 in fig. 1) is a radio rheostat of about 25 ohms for regulating the filament voltage (set at 1.9 volts) as indicated on the voltmeter, to the left in figure 2; no. 4 (R_4 in fig. 1) consists of a group of resistors arranged for reducing the sensitivity of the microammeter, and thus protecting the meter while the preliminary adjustments are being made; no. 5 (R_g in fig. 1) is similarly connected with a group of high grid resistances, for controlling the current sensitivity of the instru-

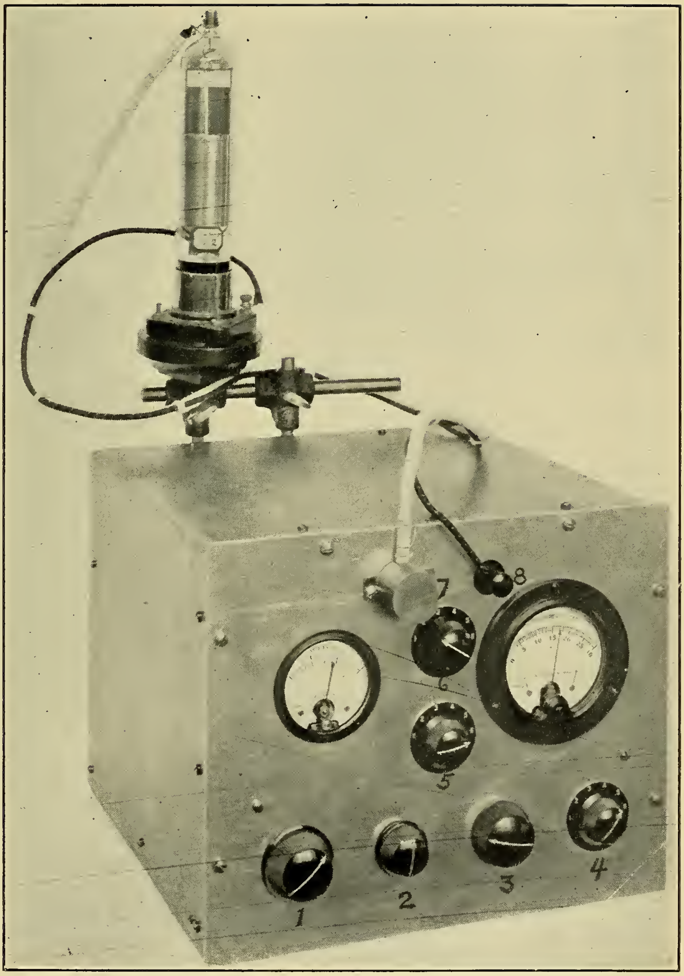

Figure 2.—*Portable ultraviolet intensity meter.*

ment (i.e., for controlling, in five steps, the current through the micoammeter when the photoelectric cell is irradiated; and no. 6 (P_2 in fig. 1) is used for determining the voltage sensitivity of the amplifier, which is read as an arbitrary deflection on the microammeter.

Since a suitable shielded cable was not available for connecting the photoelectric cell to the amplifier (nos. 7 and 8, in fig. 2) one was constructed. For the cathode lead an ordinary lamp cord wire was drawn through a section of heavy rubber tubing and this wrapped with no. 26 cotton-covered copper wire, which was grounded to the metal box. Shielding of the anode wire is unnecessary since it has a definite potential and low impedance to ground. The photelectric cell support (when not mounted on the amplifier box) is connected to the box by means of an auxiliary grounding wire.

For the use of this instrument as an ultraviolet (dosage) intensity meter, employing commercially available photoelectric cells, and applying it to various sources of ultraviolet in use, it was found that an overall range in current amplification of 100 to 20,000 was sufficient for all practical purposes. Higher or lower ranges of amplification could be easily obtained by using higher or lower values of R_g (fig. 1), or by using a more or less sensitive indicating meter.

The constancy of the resistors (R_g in fig. 1) is determined, from time to time, by comparison with our standard Thomson galvanometer sensitivity testing device (8).

III. PERFORMANCE TESTS

Using a balanced thermopile and filter radiometer, (calibrated against a standard of radiation) (2), and data on the spectral energy distribution of the source, it is possible to evaluate the ultraviolet in different sources in absolute units. This instrument is therefore used as a primary standard (6) for calibrating selective radiometers (photoelectric cells) in absolute value. Such a calibration of the indicator (microammeter, in the present case) scale of an ultraviolet (dosage) intensity meter is necessary for each kind of source used.

For example, using a certain kind of photoelectric cell, insensitive to ultraviolet of wave lengths longer than 334 $m\mu$, in a Corex *D* glass bulb, which is opaque to radiation of wave lengths shorter than 280 $m\mu$, the factors for converting the microammeter scale reading into microwatts per square centimeter of radiation of wave lengths shorter than 313 $m\mu$, were 1.94, 12.4, and 18.5, respectively, for the sun, the *S*–1 lamp and the "Therapeutic C"–carbon arc lamp.

The large factor for the "C"–carbon arc is owing to the large amount of radiation in the spectral region of 220 to 260 $m\mu$, emitted by the lamp (6) but excluded from the photosensitive material contained in the glass bulb, which is opaque to radiation of wave lengths shorter than 250 $m\mu$.

Photoelectric cells of titanium, uranium, cadmium, etc. (7) which are insensitive to radiation of wave lengths longer than about 330 $m\mu$, appear to be applicable to the measurement of the short wave length ultraviolet of a greater variety of sources than the photoelectric and "photronic" cells, which have their maxiumm response in the visible spectrum, and are sensitive to the near infrared. The latter type, however, is simpler to operate and is satisfactory where high precision is not required.

The necessity of calibrating the photoelectric cell, in absolute value, against a standard nonselective radiometer is unavoidable. Accepting this as necessary for all selective radiometers the two outstanding desiderata are; (*a*) that the indicator of the ultraviolet dosage intensity meter shall have a stable zero reading and (*b*) that the scale reading shall be linear. An instability of the zero reading may be owing to electrostatic disturbances, and to temperature changes in the amplifier.

Performance tests, made in the field and in the laboratory, show that the indicator (microammeter), of the herein described ultraviolet intensity meter, has a stable zero reading, after it has been operated for 5 to 10 minutes, to permit the temperature of the amplifier tubes to come to equilibrium. During this interval the voltmeter setting (1.9 volts) may increase by a perceptible amount that is eliminated by readjustment of the rheostat, R_3 in figure 1.

After this preliminary adjustment to equilibrium, no shifting of the zero of the indicator (microammeter) occurred either when testing the amplification sensitivity of the instrument (by unbalancing the circuit by means of the switch P_2 in fig. 1), or when making measurements of ultraviolet intensities by means of the photoelectric cell.

The linearity of the indicator (microammeter) scale reading was found accurate within the tolerance (±1 percent) in accuracy of the particular microammeter used. This is higher than is required relative to the constancy of the ultraviolet output of the sources in common use; especially of sunlight, at sea level, which is subject to large fluctuations in intensity with slight changes in atmospheric conditions. Hence, for all practical purposes, nothing would be gained by using a null method for measuring the photoelectric current.

In conclusion, it is relevant to add that, in this preliminary study, the indicator employed was an inexpensive microammeter (Weston, model 600), which is sufficiently accurate for ordinary use. Placed in a vertical position, as indicated in figure 2, the needle was slightly unbalanced, producing slight irregularities in the scale reading. As a highly accurate measuring instrument, for investigating atmospheric transmission coefficients, etc., it is proposed to replace the present indicator by a precision microammeter (Weston, model 440), used in a horizontal position in order to take full advantage of the highest accuracy that is attainable.

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